How Cell-phone Implants Work

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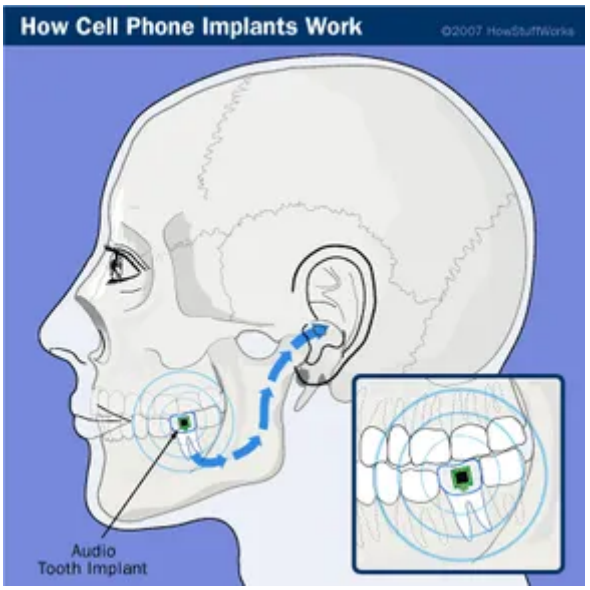

The jawbone can transmit vibrations from the tooth to the ear.

In November 2002, designers at the Royal College of Art in London made headlines after coming up with the world's first cell-phone implant. Their design involved a small chip that housed a receiver and a transducer. The receiver could pick up mobile phone signals, and the transducer could translate them into vibrations.

Once implanted in a person's molar, the transducer caused the tooth to vibrate in response to radio signals. The physical structure of the jaw carried the tooth's vibrations to the inner ear, where the user, and no one else, could perceive them as sound. The implant's designers held dramatic demonstrations of this principle using a vibrating wand. Participants confirmed that they could hear crystal clear voices through

their teeth.

The designers used a wand for the demonstrations rather than the implant itself because the implant did not actually exist. It was a concept, not a real device. In addition, it wasn't really a phone -- it was more like one of the Bluetooth earpieces commonly used today. It had no mechanisms for dialing, storing phone numbers or anything else that a phone can do, other than relaying sounds to the listener. The theoretical implant's design didn't even allow the user to speak to the party on the other end of the line.

Even though it wasn't actually a working phone, the Royal College of Art project got people thinking about implantable phone technology. Cell phones have gotten a lot smaller since they hit the market, so one that is small enough to fit inside a person seems inevitable. The recent preponderance of tiny, functional Bluetooth earpieces has also made the idea of a discreet, permanent implant seem viable to a lot of people.

But even though they're a lot smaller than they used to be, modern cell phones are still far too big to fit inside your body. Even the smallest Bluetooth earpieces are really too big to fit anywhere other than your abdomen or chest. In either of these locations, a cell phone would be impractical, inconvenient and dangerous. Implanting one would require major surgical procedures under general anesthesia.

For these reasons, developers had to make numerous modifications to existing cell phone designs to create a complete, working cell-phone implant. Rather than using a single piece inserted under a person's skin, cell-phone implants are **modular** in design. Implantation requires several small, separate incisions and local anesthetic. The different pieces communicate with each other using flexible circuitry and conductive tattoo ink, and each piece is specially designed to be as small and comfortable as possible.

In this article, we'll look at all the parts of the cell-phone implant and how they communicate with each other. We'll also examine the pros and cons of making your phone part of your body.

Is This For Real?

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2002, but that's as far as it goes. Now that April 1 has come and gone, we'll admit that this article is absolutely untrue...for now.

Cell-phone Implant Modules

If you remove a cell phone's plastic exterior, you'll find all kinds of electronic components inside. Numerous chips and devices attach to a printed circuit board. These include:

- A **microprocessor**, which acts like the phone's brain
- **Flash memory** and **read-only memory (ROM)**
- **Analog-to-digital** and **digital-to-analog** converters
- A radio**transmitter** and **receiver**
- A **speaker** and a **microphone**

Some models have **GPS** and **Bluetooth** receivers. Many new phones also have built-in **digital camera** lenses and sensors, as well as storage space for pictures and videos. Some phones even have the circuitry and storage space required to store and play MP3s. The more parts there are and the more impressive the phone's capabilities, the larger and stronger the phone's battery has to be. In many cell phones, the battery as almost as large as the printed circuit board it powers.

Combined, the circuit board, its components and the battery make up about half of the phone's bulk. The rest comes from the screen, the keys and the outer plastic case. Since an implant has to be much smaller than a traditional cell phone, a good first step in making one is getting rid of these three elements. For this reason, a cell-phone implant does not have a typical **user interface (UI)**. It uses the person's body instead.

Taking the place of a keypad is a **six-axis piezoelectric accelerometer** attached to the angle of the **mandible**, or the jawbone. This accelerometer can detect when the jaw opens and closes or moves from side to side. Since the jaw moves along with a person's head, the accelerometer also detects head movements. It does this using crystals that create electrical pulses when they change shape. You can read How the Nike + iPod Works to learn more about these crystals.

The implant's on/off switch

After receiving the cell-phone implant, the user learns a series of head and jaw **gestures** that control the phone. This is similar to the stylus shorthand used with older PDAs. It's also a little like sign language, but it uses the head and jaw instead of the hands. Before beginning a gesture, the user touches a small **on/off switch** located on the mastoid process, a bony protrusion on the skull just behind and below the ear. This lets the implant know to be ready for the user's input and prevents it from mistaking ordinary conversation or movement for gestures. The user can

also turn the implant completely off by holding the switch down for three seconds.

The modules of a cell-phone implant are inserted under the skin and in the jaw.

During a gesture, a flexible circuit and conductive ink carry the accelerometer's electrical impulses to the implant's microprocessor, located on the back of the ear. This processor, made of a **flexible thin-film transistor**, is a custom-fitted piece that lies precisely along the cartilage in the back of the ear. The processor uses a **lookup table** stored on a nearby ROM chip to match a person's movements with the cell phone's commands. If a person makes the gesture for "four," the processor finds the corresponding pattern of electrical impulses in the lookup table. It then holds the number four in a **memory buffer** until all of the gestures are complete. An implanted **radio frequency (RF)** transmitter sends the data using radio waves. This data moves just like ordinary cell phone data -- check out How Cell Phones Work to learn about the process.

The keyboard is just one part of a cell phone's typical user interface. Learn how cell-phone implants get by without a screen in the next section.

Thin-film Transistors and Is This For Real?

If your current cell phone has an LCD screen, it probably uses thin-film transistors (TFTs) to power its pixels. The TFTs used in cell-phone implants are a little different, though. The TFT in an LCD screen is under a pane of glass, so it's rigid. The TFTs used in cell-phone implants, on the other hand, are attached to flexible film. This technology, developed by the U.S. Air Force research lab, was originally intended to provide soldiers with flexible, wearable displays.

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Adapting Components

Piezoelectric transducer ring

Early cell-phone implant prototypes had functioning screens made from organic light-emitting diodes (OLEDs) implanted in the back of the hand. However, this system had a number of drawbacks:

- Hand injuries, exposure to extreme weather and even excessive hand washing quickly led to screen failure.
- The OLED required its own battery and recharging system.
- Users expressed concerns that the constant presence of radio waves traveling between their head and hand would cause health problems.

Developers rejected the idea of a stand-alone, non-implantable screen on the grounds that it kept the phone from being a true implant. It also eliminated one of the implant's major benefits. With a stand-alone screen, people still had a component that they had to carry around and could potentially forget or lose.

In the end, developers decided to make the implant's speaker take the place of the screen. The custom-fitted speaker is a thin crescent of piezoelectric transducers, or objects that change their shape when exposed to electrical impulses. It fits inside the wall of the ear canal and stimulates the skin near the **tympanic membrane**, or eardrum. The eardrum picks up these vibrations, and the user's brain interprets them as sound.

The speaker, like the accelerometer, relies on a lookup table located in the ROM to provide audible feedback to the user. For example, when a person makes the gesture for "eight," the processor uses one lookup table to interpret the gesture and another to determine which sound to play. Then, speaker plays the word "eight." This allows the implant to audibly confirm each of the user's gestures, cutting down on misdialed numbers and other errors. The piezoelectric speaker also relays the other end of the conversation to the user.

In order to cut down on processor and memory requirements, the device relies on recorded responses rather than text-to-speech technology. The implant's ROM comes pre-loaded with:

- All of the letters of the alphabet, used to relay text messages
- Pound, star and numbers zero through nine
- The phrase "Contacting emergency services," which pairs with an emergency gesture used to dial 9-1-1
- Basic commands, such as "hang up," "start new call" and "check voice mail"

The ROM chips, along with the other integrated circuits used in the implant, look a lot like the ones you'd find in a typical cell phone. The RF transmitter and receiver, processors and analog-digital converters are all small, relatively flat chips that attach directly to the flexible circuitry. The most noticeable difference is that these chips are often somewhat rounded rather than completely square or rectangular. This makes them less obtrusive and more comfortable under the skin.

The edges of many cell-phone implant components are rounded rather than completely square.

For the most part, these components aren't noticeable. They don't rub

against eyeglass earpieces or snag on hair. However, two components can cause difficulties for people who wear earrings. The implant's microphone rests just under the skin in the lower portion of a person's earlobe. An earring's weight pushes on the microphone, making it visible through the skin and causing discomfort. The implant's **antenna** is a wire that matches the curve of the **auricle**, or the outer portion of the ear. Some users find that earrings worn along the auricle become uncomfortable after implantation, especially if they rub against the skin above the antenna.

The antenna of a cell-phone implant fits along the auricle of the ear.

Next, we'll look at the battery power that keeps this system running.

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Power and Signals

The cell-phone implant's microphone is tiny and fits in the earlobe.

Manufacturing small microphones and rounding the edges of microchips is relatively easy. Powering an implanted electronic device, on the other hand, isn't. Most current cell phones use lithium-ion batteries that are simply not suited to implantation in a person's body. First, they're too big -- most cell phone batteries, while relatively thin, are at least a few inches square. Second, the more compact the battery is, the thinner and more prone to failure its internal components are. Third, even the most efficient cell phone batteries lose power quickly during conversations. They have to be recharged frequently, sometimes for hours at a time. Finally, ordinary cell phone batteries are not safe for such a use.

A pacemaker

PUBLIC DOMAIN IMAGE

Developers first turned to medical technology for a solution to the battery problem. The proposed solution involved **pacemaker batteries**, which can power a person's pacemaker for years. However, these batteries, which use lithium iodide rather than a lithium-ion battery's combination of lithium and carbon, turned out to be far too expensive. In addition, a pacemaker uses a relatively small amount of electricity, administered at intervals, to keep a person's heart beating regularly. A cell phone, on the other hand, needs a sustained source of power. Developers wound up with dead batteries and no way to recharge them.

The second attempt involved an array of very small batteries wired in series under a person's scalp. Users could recharge these batteries using **inductive coupling**, the same method used to recharge most electric toothbrushes. The recharging cord attached to the array magnetically, without piercing the skin. Unfortunately, fully charging a depleted battery took hours, and members of early test groups protested about the need to stay in one place during that time. Those who tried to recharge their batteries while sleeping often dislodged their cords accidentally or experienced vivid, disturbing dreams.

The cell-phone implant's flexible battery array

Finally, developers decided that the best option was to use the body's

own energy to recharge the implant's batteries. They created a **Seebeck-effect** strip that transforms body heat into electricity. This device, a curved strip that fits in the space between the ear and the scalp, is the implant's only external component. Its positive and negative electrodes, which are hermetically sealed to prevent water entry and corrosion, penetrate the skin at the top end of the strip. By lifting a tiny, embedded latch at the bottom of the strip, the user can user pull it away from the skin for cleaning.

The recharging strip uses layers of two separate metals to turn a person's ear into a **thermoelectric generator**. The piece of metal in contact with the skin is warmer than the piece in contact with the air. This creates a thermocouple, which produces a current. Watch manufacturers have used a similar system to create self-recharging wristwatches.

The implant's recharging system connects to a serial array of batteries arranged in a grid under the user's scalp. These batteries are small and round, so they are less obtrusive than the large, flat batteries used in most cell phones. The thermocouple strip also has a very low profile, but it can cause eyeglasses and sunglasses to sit slightly askew, requiring adjustment to the earpieces.

The Seebeck-effect generator prior to custom fitting

The Seebeck-effect generator charges a person's implant batteries constantly, so there's no need to plug in. However, if the batteries become fully depleted during an extended conversation, it can take

several days for the generator to bring them back to full power. This is one of the challenges that cell-phone implants still face. We'll look at others in the next section.

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Cell-phone Implant Pros & Cons

Receiving SMS messages requires users to keep careful notes.

The Seebeck-effect recharging system can generally keep a person's cell-phone implant running. However, the prolonged recharging time can force users to limit conversation length or the number of calls they make in a short period of time. The battery power and the relatively small amount of available space in which to implant components also reduces the number of bells and whistles the phone can have. For example, since there's no screen, you can't take pictures, watch movies or play games using a cell-phone implant.

You also can't get turn-by-turn GPS directions, since the system has no GPS receiver. However, in the United States, cellular phones must be able to transmit their locations to public safety answering points when people dial 9-1-1. When a person calls 9-1-1 using a cell-phone implant, the cell phone network uses the signal's angle of approach to two or more towers to determine a user's location. This location-tracking ability has raised concerns among privacy advocates. For some people, the idea of a permanently imbedded device that can report a person's location can be unnerving.

The implant does retain one commonly-used cell phone feature -- SMS messages. The process of sending text messages, though, is a little complex. The user must first press the on/off switch, then perform the right gesture to activate the phone's SMS mode. He must then make the gesture for each letter in the message, followed by a gesture designating the end of the message. The next series of gestures lets the implant know the number to which to send the message. When receiving a message, the implant reads off the incoming data letter by letter, making it advisable for users to carry a pen and paper so they can make sense of their messages.

Developers originally intended to use a piezoelectric accelerometer implanted in the tongue to provide a user interface. That way, all of a user's gestures could take place in the privacy of his own mouth. However, connecting the sensor to the rest of the circuitry proved to be a challenge. Users in early studies experienced long recovery periods, persistent swelling and reduced speech clarity. Because of the tongue's near-constant motion and the distance between it and the ear, connecting circuits were prone to failure.

This led to the decision to place the accelerometer on the jawbone and to the use of head and jaw gestures. Although designers say the system is easy to learn, many users report that using it makes them self-conscious.

Common analogies involve feeling like a cow chewing cud or a reject from the 1980s hair metal scene. In addition, some users have reported hitting the on/off switch while showering, brushing hair, inserting earrings or performing other tasks, causing the implant to interpret ordinary movements as gestures. In some cases, this has led to battery depletion as the user unknowingly transmitted private conversations and sensitive activities to friends' or relatives' voice mail.

In addition, the implant carries a number of safety precautions. Users cannot undergo MRI procedures because of the implants' metal components. The electronic components and batteries are hermetically sealed, but a few injuries have been reported due to seal failure or damage during accidents. In addition, a few users have reported allergic reactions, swelling or bald spots over the batteries, which are the only components that are generally installed under normal hair growth.

In spite of these challenges, the success of the cell-phone implant has opened the door for a variety of other implantable electronic devices. These include MP3 players, pedometers and digital cameras.

Cell-phone implants, sold under the brand name Voltaire, should be available in April 2007. To learn more about cell-phone implants, other types of phones and related devices, check out the links on the next page.

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